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A navigation and identificationsimulated chemicals using autonomous mobile robot with ceiling camera and onboard micro-spectrometer

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ABSTRACT

This paper proposes a method for controlling a mobile robot using decentralized control based on signal from ceiling camera to remotely recognize simulated chemicals by color sensing. This camera recognizes a tag put on the robot to specify the coordinate of the target, and sends it back to a master computer. Based on this signal, the master computer controls the robot to the coordination center where a chemical is put. Whenever moving to the expected position, the robot will open the gripper and grip the target. A slave computer analyzes the signal from an on-board spectrometer to recognize the target and send the result to the master ones. The experiment results proved the applicability of mobile robots to identify unknown targets.

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1 INTRODUCTION

The remote sensing and analysis of the chemical in the environment (drinking water quality assurance, explosives detection, etc.) had been paid a great attention all over the world. In the field of recognition and identification, fiber sensors and neural network recognition are used to detect ultra violet demonstrated by (Lyons *et al*., 2004). In fluorescent sensor applications, tapering of a polymer optical fiber is combined with a side-illuminated setup to increase fluorescence signal by Pulido and Esteban (2010). Another method is using neural network to predict the absorption and fluorescence spectra (Kuzniz *et al*., 2007). This method needs a large database and time for training offline. The similar idea using neural network to predict the new spectra measurement from unknown buffer solution is proposed (Suah *et al.,* 2003). The development for the analysis of differential mobility spectra is to use a genetic algorithm based pattern recognition to classify various chemical mixtures in dilute solution by Eiceman *et al*., 2006. These researchers use different methods for recognition the chemical, but none of them combines chemical to mobile robot system.

In mobile robot field, a method using mobile robot to measure ammoniac in atmosphere vapor was proposed (Anderson *et al.,* 2006). This application simulated the environment in Mars. In addition, a method for mobile robot tracking and gripping the target by using stereo camera and manipulator was proposed by Hieu and Hung (2015). The camera was used for tracking while the arm does the rest. These papers had just only gripped the target and measured the ammoniac in atmosphere, they could not recognize other chemical forms.

This paper proposes a method for remote sensing and analyzing simulated chemicals in environment by a mobile robot. The mobile robot is controlled by using decentralized control system. One master computer controls robot moving in a coordinate system created by a ceiling camera. Whenever moving to expected position, robot grips the target automatically. After that, the spectrum is calculated by a slave computer and a spectrometer. Finally, the data is sent back to the master, so controller could know the type of the target.

2 METHODS

2.1 System overview

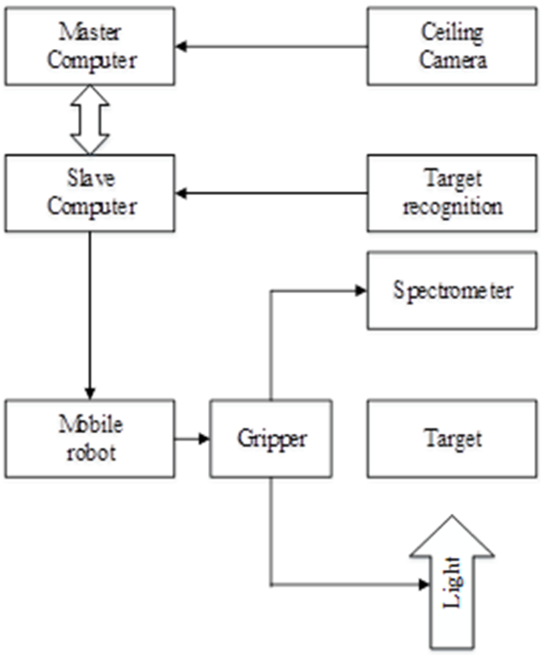


Fig. 1: System overview

The system overview is shown in Figure 1. A mobile robot is controlled by one decentralized system including master-slave computer systems. The master stays in the control station while the other is put on the robot. The master computer controls the robot moving to central of the map by using signal from a ceiling camera. Whenever robot moves to the expected position, it starts gripping the target which contains a chemical. The slave computer receives signal from spectrometer and sends it back to the master, so the controller can know what kind of chemical inside the target.

2.2 Camera calibration

Camera calibration is a proceed that transforms image of scene from 3D to 2D, and describes the physical manner. Perspective projections of the camera and the human eyes can be regarded as a pinhole model which is shown in Figure 2.

It is seen in Figure 2 that$(x_w,\ y_w, z_w)$ represents position of P point in 3D world coordinate, and $(x_c,\ y_c, z_c)$ represent position of P point in 3D camera coordinate, the f is camera focal length.

According to the theorem of similar triangles, the perspective projection can be formulated as:

$$\frac{Y_d}{f} = \frac{Y_c}{Z_c};\ Y_d = \frac{fY_c}{Z_c} \tag{1}$$

$$\frac{X_d}{f} = \frac{X}{Z_c};\ X_d = \frac{fX_c}{Z_c} \tag{2}$$

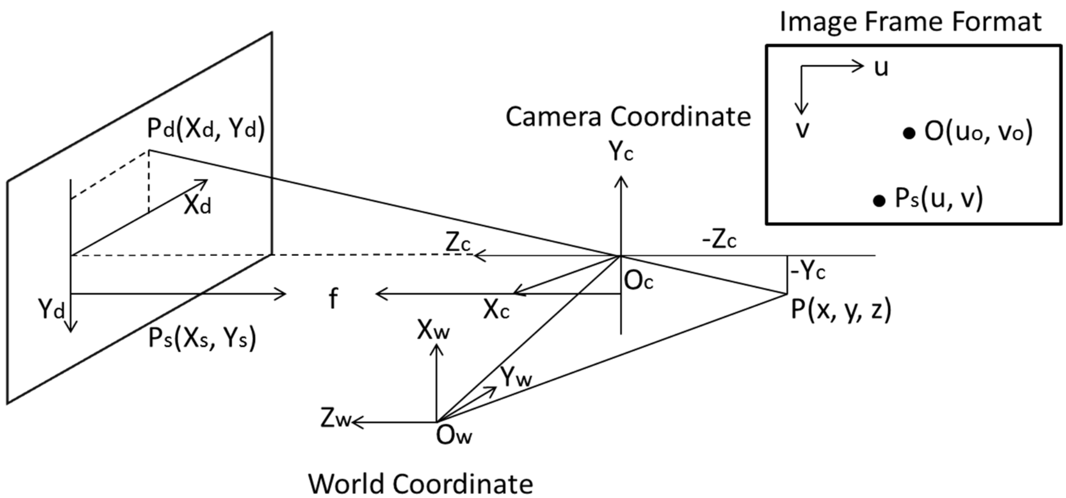


Fig. 2: Camera calibration model

Through camera model transform, the P component in the image plane can be solved as follows:

$$\begin{bmatrix} X_d \\ Y_d \\ 1 \end{bmatrix} = \begin{bmatrix} f/z_c & 0 & 0 \\ 0 & f/z_c & 0 \\ 0 & 0 & 1/z_c \end{bmatrix} \begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} \tag{3}$$

In the real application, the radial distortion of the image plane is amended to read:

$$\begin{aligned} x_s &= x_d(1+kr_s^2) \\ y_s &= y_d(1+kr_s^2) \\ r_s^2 &= x_s^2 + y_s^2 \end{aligned} \quad (4)$$

Where: k is lens distortion coefficient.

The Mapping relationship between camera coordinate and pixel coordinate as shown:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} N_x f & 0 & u_0 \\ 0 & N_y f & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} = \begin{bmatrix} \alpha & 0 & u_0 \\ 0 & \beta & v_0 \\ 0 & 0 & 1/z_c \end{bmatrix} \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} = C \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} \quad (5)$$

Where$\alpha = N_x f,\ \beta = N_y f,\ C = \begin{bmatrix} \alpha & 0 & u_0 \\ 0 & \beta & v_0 \\ 0 & 0 & 1/z_c \end{bmatrix}$, $N_x$and N_y are the number of pixels of unit length; u_0 and v_0 are principal pixel in camera coordinate and$C$ is intrinsic matrix, through the camera internal parameter matrix can be derivation pixel coordinate $[u, v, 1]^T$ from camera coordinate $[x_c, y_c, z_c]^T$.

In addition, the coordinate system relationship between camera and world obtained is through rotation and moving, and transformation relationship as shown:

$$\begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix} = \begin{bmatrix} R_{3\times3} & T_{3\times1} \\ 0_{1\times3} & 1 \end{bmatrix}_{4\times4} \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} \quad (6)$$

where R is rotation, and T is translation. The relationship between the both matrixes is called the extrinsic matrix, and combined with the camera's intrinsic matrix can be calculate transformation matrix between world coordinate and pixel coordinate as shown:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = C \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} R_{3\times3} & T_{3\times1} \\ 0_{1\times3} & 1 \end{bmatrix}_{4\times4} \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} = C[R \quad T] \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} \quad (7)$$

Through equation (**Error! Reference source not found.**) can define 3×4 projection matricesK, $K_{3\times4} = C[R \quad T]$.

2.3 Target recognition algorithm

The Minimum Bounding Rectangle (MBR),which is used to simplify model of 2D objects, extracts easily its characteristics. The MBR of geometry which is the bounding geometry formed by the minimum and maximum coordinates can be constructed in the following steps (Figure 3) as presented by Papadias and Theodoridis (1997):

Constructing the convex hull;

Rotating all edges for the convex hull to the parallel position to x axis;

Calculating area of bounding rectangle;

Finding the minimum of the rotation rectangles and rotate it back to normal.

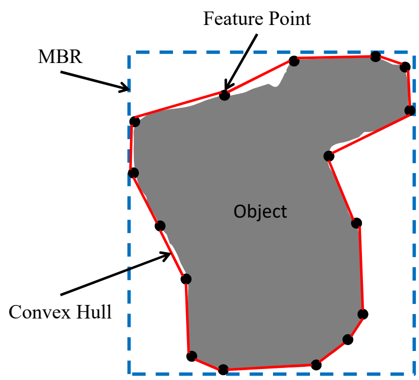


Fig. 3: MBR schematic diagram

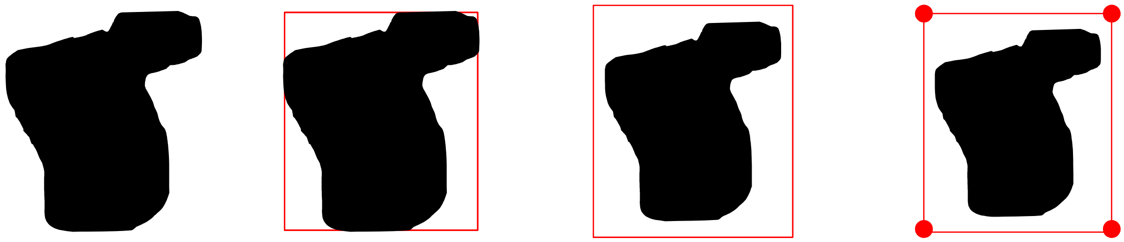
The above method is used to detect a robot's tag (Figure 3). It is put on middle robot and detected by a ceiling camera. The position of robot's tag is the same as position of mobile robot on the map. A top-hat filter is used to find out the ranked value from two different size regions. The brightest value in a rectangle interior region is compared to the brightest value in a surrounding annular region. If the brightness difference exceeds a threshold level, it is kept (otherwise it is erased). "The kept" region is the definition of the tag position and direction.

In order to avoid uncertainties of the object shape, MBR that covers the entire obstacle is used to simplify 2D model robot tag. In the actual operation, this is easier to extract obstacle's corner feature, and reduces the computing time. Process of obstructions evolution is shown as in Figure 4 which follows by 3 steps:

From original target, it is applied the MBR algorithm.

Apply morphological dilation and erosion to moderate the image.

Finally, it is extracted the corner of the bounding box.



(A)Original obstacle (B)MBR operating (C)Moderately dilated (D)Corner extraction

Fig. 4: Obstacle feature extraction after MBR

Center of area (CA) is very similar to center of mass (CM), but CA has better extraction feature point in the geometric shape of the graphic. For the target feature extractions, CA is often used to find target feature point coordinates in 2D plane. When a complex geometry can be divided into a number of known simple geometry, first step is calculation the area centers in various parts of the entire graphics, and then the center of target by the following general formulas (2) and (3):

$$Cr_x = A + \frac{W}{2}, \quad (8)$$

$$Cr_y = B + \frac{H}{2}, \quad (9)$$

where Cr_x and Cr_y are CA in 2D coordinate plane which is shown in Figure 5.

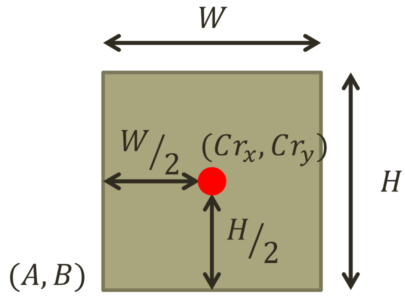


Fig. 5: Target object of center of mass

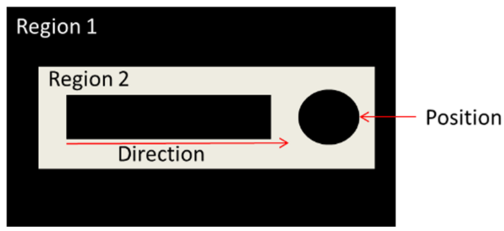


Fig. 6: Robot tag design concept

In Figure 6, center of the circle represents robot's x and y coordinates as$Robot_{(x,y)}$, and the center vector which is connected between a rectangle and circle is represent robot's heading angle as $\theta_{Heading\ angle}$in the ground coordinate.

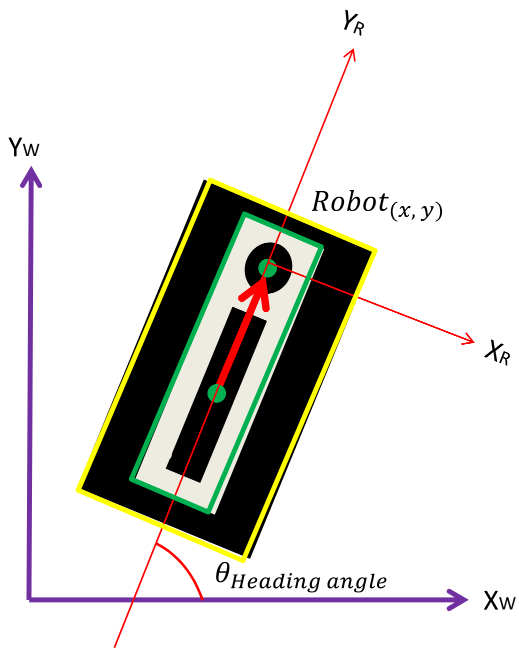


Fig. 7: Robot tag the coordinates defined

2.4 Kinematic model of mobile robot

Let consider a robot at an arbitrary position and orientation, and an expected position and orientation (goal) (Figure 7). The actual pose error vector given in robot reference frame $\{X_R \quad Y_R \quad \theta\}$ is $e = [x \quad y \quad \theta]^T$ with x, y and θ is the expected position and heading angle of the robot.

The kinematics of a differential-drive mobile robot is described by equation (10):

$$\begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{\theta}\end{bmatrix} = \begin{bmatrix}cos\theta & 0\\ sin\theta & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}v\\ \omega\end{bmatrix}, \quad (10)$$

where:

v is linear velocity of the robot,

ω is angular velocity of the robot,

θ is the heading angle of the robot,

$\dot{x}$ and $\dot{y}$ are the linear velocities in the direction of $X_I$and Y_I of the initial frame.

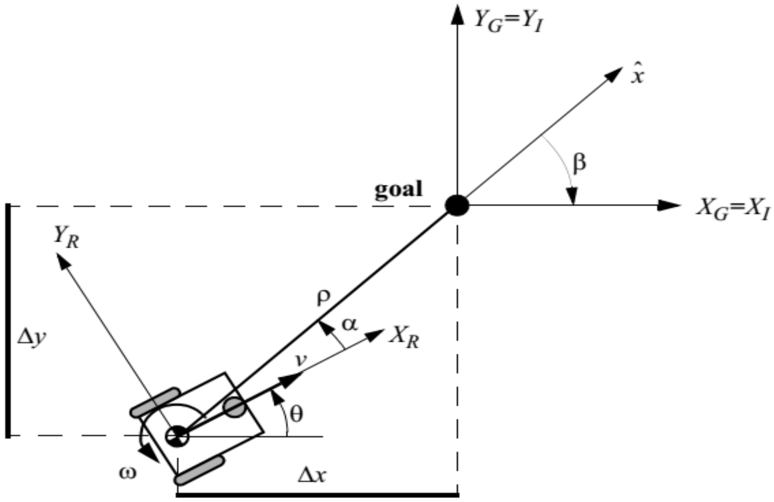


Fig. 8: Kinematic transformation coordinates

Coordinates transformation into polar coordinates with its origin at goal position, followed Figure 8, and are shown as in equations (5-7):

$$p = \sqrt{\Delta x^2 + \Delta y^2}, \quad (11)$$

$$\alpha = -\theta + atan2(\Delta y, \Delta x), \quad (12)$$

$$\beta = -\theta - \alpha. \quad (13)$$

where β is the goal angle of mobile robot.

System description in the new polar coordinates becomes as presents in equation (14):

$$\begin{bmatrix}\dot{p}\\ \dot{\alpha}\\ \dot{\beta}\end{bmatrix} = \begin{bmatrix}-cos\alpha & 0\\ \frac{sin\alpha}{p} & -1\\ -\frac{sin\alpha}{p} & 0\end{bmatrix}\begin{bmatrix}v\\ w\end{bmatrix}. \quad (14)$$

2.3 Micro-spectrometer

A spectrometer is an instrument measuring the properties of light over a specific portion of the electromagnetic spectrum. Measured variable is often light's intensity. The independent variable is usually the wavelength of the light. In this experiment, the system consists of a mobile robot attaching one onboard spectrometer and high luminance white LED (Figure 9) to test various liquid samples. Each color has a specific wavelength where around this wavelength the intensity is maximum. The absorbance color is according to equation (15) The patterns of the different solution are feed to the pattern recognition algorithm to train the model.

$$A = -\log\left(\frac{I}{I_0}\right), \quad (15)$$

where

I isintensity of transmitted light,

I_0 isintensity of incident light,

A is absorbance.

To recognized the simulated chemicals, root mean square error (r.m.s) is applied. Following Ross (2009), in general, this method predicts the average y value associated with a given x value. To constructs the r.m.s error, the residuals, difference between the actual values and the predicted values, must be determined by the equation $\hat{y}_i - y_i$.

Where

$\hat{y}_i$ is the observed,

y_i is the predicted value.

Then, the r.m.s is used as a measurement of the spread of the y values about predict the y value:

$$RMSErrors = \sqrt{\frac{\sum_{i=1}^{n}(\hat{y}_i - y_1)^2}{n}} \quad (16)$$

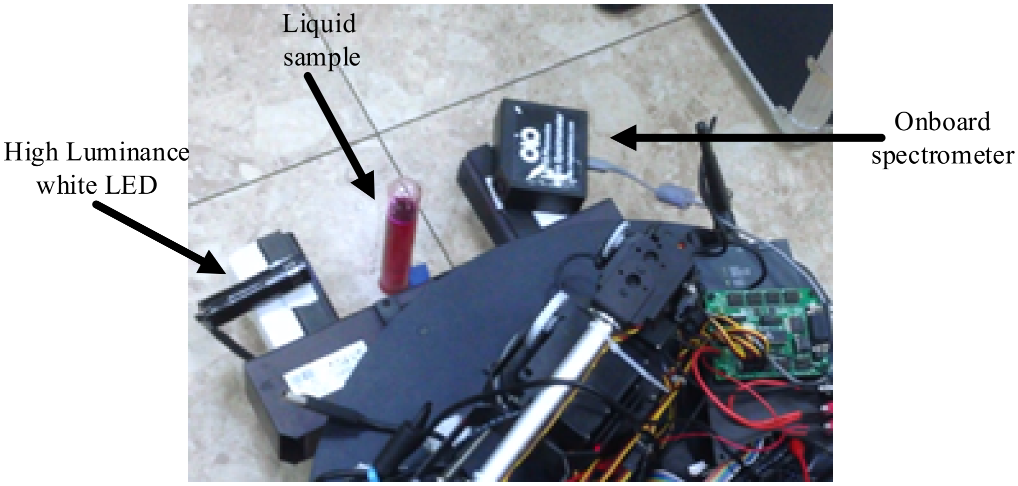


Fig. 9: Spectrometer system

3 RESULTS

3.1 Mobile robot

Robot's tag is shown in Figure 9. The robot position is identified by the red circle, so signal from a camera allows controller to know the position of the robot in the map coordinates. It also shows the position of robot in the map (Figure 10)when robot is at $(x, y) = (-1071, 23)\ mm$ with the heading angle $\theta = -9{,}1\ rad$).

Fig. 10: Simulation the position of Robot (mm)

Figure 11 presents the position of robot moving from 12 unknown positions to the central O(0, 0). It is seen that, although there are some noises, the kinematics algorithm can control the robot from random position to the central with high accuracy.

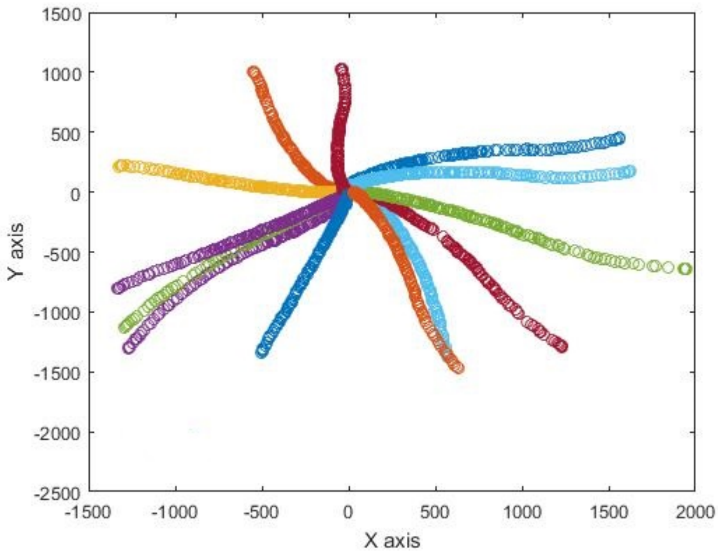


Fig. 11: Robot trajectory tracking

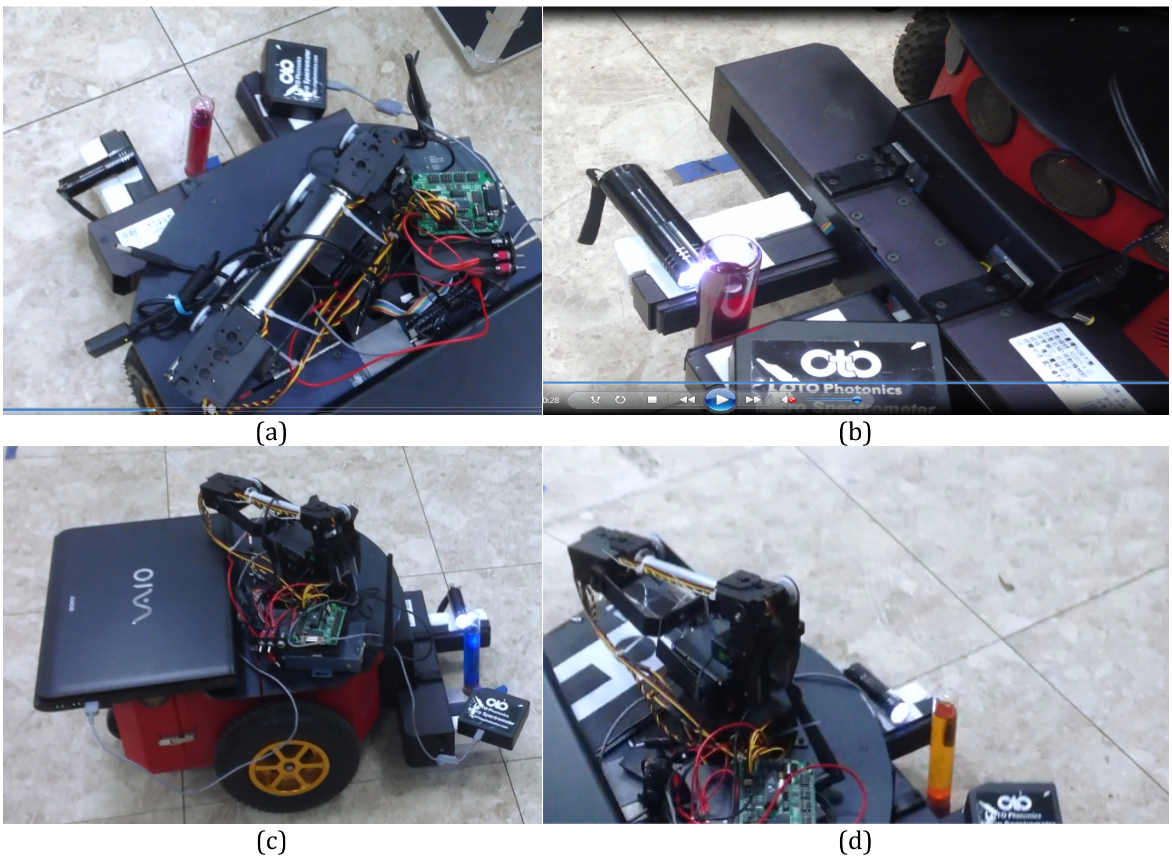


Fig. 12: (a), (b), (c), (d). Robot grip the target

Whenever robot moving to the central, where the solution liquid is put in an experimental pipe, it grips the target automatically. This proceeding is shown in Figure 12 (a), (b), (c), (d). In Figures 12(a), (b) the solution is red while (c), (d) it is blue and yellow.

3.2 Target recognition

Data from a spectrometer is an array of number. From these values, root mean square errors are applied to find out the solutions. These are also for plotting intensity graph (Figure 13). Figures 13(a), (b), (c) present the intensity of three different kinds of color liquid: red, yellow and blue. The peak of them are around 675-720, 600-620, and 450-500, respectively. By comparison with Table 1, these values do not get a high accuracy but they can be accepted. There are many reasons for this error: noises from light or the light intensity is not strong enough. The last figure presents the situation when robot cannot grip the target.

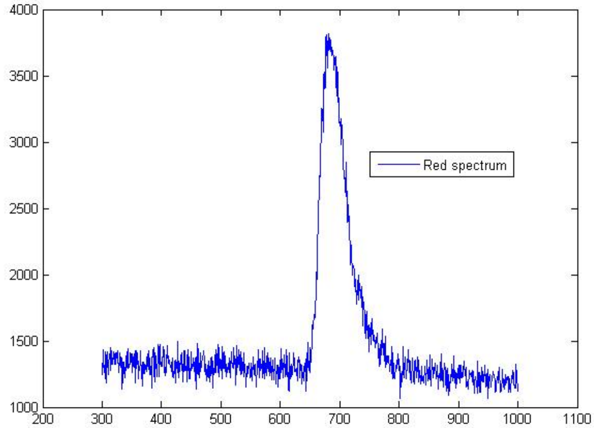


Figure 13(a)

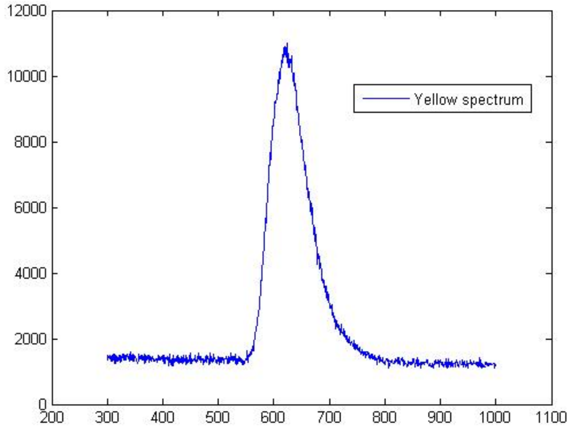


Figure 13(b)

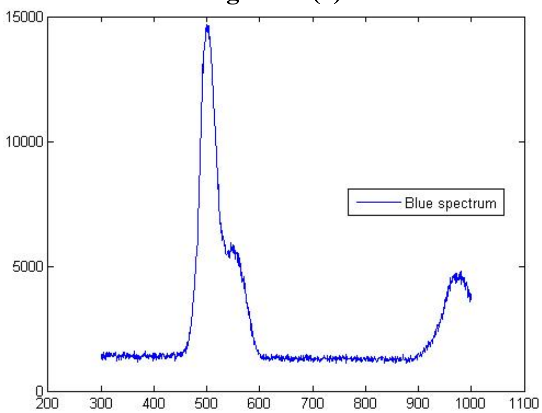


Figure 13(c)

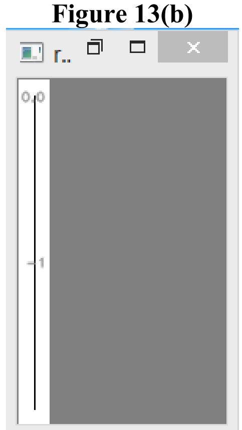


Figure 13(d)

Fig. 13: Intensity of different kind of colors

The peak of these values in Figure 13 are compared with the values in Table 1. Computer concludes the results by comparison the closet value between the peak and frequency of colors.

Table 1: The frequency and wavelength of some popular color

Color	Frequency	Wavelength
Violet	668-789 THz	380-450 nm
Blue	631-668 THz	450-475 nm
Cyan	606-630 THz	476-495 nm
Green	526-606 THz	495-570 nm
Yellow	508-526 THz	570-590 nm
Orange	484-508 THz	590-620 nm
Red	400-484 THz	620-750 nm

4 DISCUSSION

The results show that robot detection by recognizing the robot tag can give an accurate position. Master computer receives the robot tag position so the controller can know where the robot is. The algorithm gives a good result when robot can move to the central of the map from unknown positions. Root means square errors can help to detect the solution inside the pipe; however, if liquid sample has similar wavelength, the results maybe the same.

5 CONCLUSIONS

This paper investigated a method to remotely recognize unknown chemicals by a mobile robot in a coordinate system using image processing. The robot moved to the center coordinates and then use the device to pick up a tube. Spectrometer was used to identify the color of chemical contained in the test tube.

The experimental results showed that the robot is capable of moving to the center coordinates from many unknown locations to pick up a chemical tube. Spectral analysis devices and algorithms can analyze the color intensity of the object to recognize the type of chemical.

This study has just given a basic idea for using mobile robot for gripping and simulation chemicals. There are two main ways for improving this research topic:

Mobile robot can avoid the obstacle or path following autonomously;

Apply some model predictive to predict the chemical simulated.

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